energy, or a gas that has a large ionization cross-section, such as Ar gas, can provide a uniform electron density or plasma density.

In a first aspect of the present invention, there is provided a method of plasma-etching an organic material film formed on a substrate by means of a parallel plate type plasma-etching apparatus; wherein

the organic material film is plasma-etched with a high-frequency power of a frequency of 40 MHz or above for generating plasma, and a process gas including a gas that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above.

According to this method, since a frequency of a high-frequency power for generating the plasma is raised to 40 MHz or above, which is higher than a conventional one, a low self-bias voltage can be realized while maintaining a plasma density required for etching an organic material film, so that the organic material film can be etched with a high etching selectivity relative to an inorganic material film. Use of a process gas including a gas represented by Ar, Xe, or Kr, that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above, can significantly improve a plasma distribution, without degrading a plasma density (electron density). That is, since a gas, that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above, can be easily ionized, addition of such gas accelerates an ionization of the

process gas. Thus, the process gas can be sufficiently ionized near an edge portion of a substrate where an electric field strength is relatively low, whereby the process gas can be uniformly ionized as a whole. As a result, a uniform electron density or plasma density can be attained.

Specifically, the method can be carried out by means of a plasma-etching apparatus including a process vessel into which the process gas is supplied, and parallel plate electrodes disposed in the process vessel, the electrodes being constituted by a support electrode on which the substrate is supported, and a counter electrode that is opposed to the support electrode. By applying a high-frequency power (frequency of 40 MHz or above) for generating the plasma to the support electrode, an organic material film can be etched with less damage to an inorganic material film, due to a low self-bias voltage of the support electrode. If an absolute value of a self-bias voltage of the support electrode is 500 V or below, a high-frequency power of a frequency of 500 kHz to 27 MHz for drawing ions to a substrate may be applied to the support electrode. Owing thereto, an etching property can be enhanced by drawing ions within a degree where the ions do not damage the inorganic material film.

When a high-frequency power (frequency of 40 MHz or above) for generating the plasma is applied to the counter electrode (not the support electrode), it is necessary to apply, to the support electrode, a high-frequency power (frequency of 500 kHz to 27 MHz) for drawing ions to a substrate. Also in this case, an absolute value of a self-bias voltage of the support electrode is made 500 V or below, so as to suppress damage to the inorganic material film.

It is preferable to use any one of Ar, Xe, and Kr, as a gas that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above. In particular, Ar is most effective in that Ar has a metastable state and makes transition therefrom to an ionized state with an energy of about 4 eV, and has a larger maximum ionization cross-section. Moreover, Ar is the most inexpensive of these gases. Each of Xe and Kr has also a metastable state and makes transition therefrom to an ionized state with a low energy, and have a large maximum ionization cross-section. Specifically, a process gas including Ar, N_2, and H_2, or a process gas including Ar and NH_3 can be used.

A frequency of the high-frequency power for generating the plasma is preferably 40 MHz or above, and a frequency of 100 MHz is most preferred.

A distance between the support electrode and the counter electrode in the parallel plate electrodes (distance between the electrodes) is preferably 40 mm or below, for the following reason. That is, according to the Paschen's law, a discharge inception voltage Vs takes a minimum value (Paschen minimum value) when a product pd (product of p and d) of a gas pressure p and the distance d between the electrodes takes a certain value. The more a frequency of a high-frequency power is raised, the smaller the value of pd which determines the Paschen minimum value becomes. Thus, in a case where a frequency of a high-frequency power is relatively high, as in the present invention, the distance d between the electrodes should be reduced when the gas pressure p is constant, in order to lower the discharge inception voltage Vs to facilitate a stable

electric discharge. Therefore, in the present invention, it is preferable that the distance between the electrodes be 40 mm or below. When the distance between the electrodes is 40 mm or below, a residence time of the gas in the process vessel can be shortened. Thus, a reaction product can be efficiently discharged from the process vessel, which suppresses an etching stop.

From the same viewpoint, in a second aspect of the present invention, there is provided an apparatus for plasma-etching an organic material film formed on a substrate, comprising:

a process vessel that contains the substrate;

parallel plate electrodes disposed in the process vessel, the electrodes being constituted by a support electrode on which the substrate is supported, and a counter electrode that is opposed to the support electrode;

a process gas supply system that supplies a process gas into the process vessel;

an evacuating system that evacuates an atmosphere of the process vessel; and

a first high-frequency power source that supplies a high-frequency power for generating plasma to the support electrode; wherein

the first high-frequency power source supplies a high-frequency power of a frequency of 40 MHz or above; and

the process gas supply system supplies a process gas including a gas that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above.

Further, in the second aspect of the present invention, there is provided an apparatus for plasma-etching an organic material film formed on a substrate, comprising:

a process vessel that contains the substrate;

parallel plate electrodes disposed in the process vessel, the electrodes being constituted by a support electrode on which the substrate is supported, and a counter electrode that is opposed to the support electrode;

a process gas supply system that supplies a process gas into the process vessel;

an evacuating system that evacuates an atmosphere of the process vessel;

a first high-frequency power source that supplies a high-frequency power for generating plasma to the counter electrode; and

a second high-frequency power source that supplies a high-frequency power for drawing ions to the support electrode; wherein

the first high-frequency power source supplies a high-frequency power of a frequency of 40 MHz or above;

the second high-frequency power source supplies a high-frequency power of a frequency of 500 kHz to 27 MHz, such that an absolute value of the self-bias voltage of the support electrode is 500 V or below; and

the process gas supply system supplies a process gas including a gas that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above.

Rec'd PCT/PTO 07 MAR 2006

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view of a plasma-etching apparatus in one embodiment of the present invention;

Fig. 2 is a horizontal sectional view schematically showing a ring magnet arranged around a process vessel in the apparatus shown in Fig. 1;

Fig. 3 is a view showing the relationship between an electron energy of each gas and an ionization cross-section thereof;

Fig. 4 is a view showing the relationship between an electron energy of each rare gas and an ionization cross-section thereof;

Fig. 5 is a schematic sectional view partially showing the plasma-etching apparatus in which a high-frequency power source for plasma generation and a high-frequency power source for ion drawing are connected to a support table serving as a support electrode;

Fig. 6 is a schematic sectional view partially showing the plasma-etching apparatus in which a high-frequency power source for plasma generation is connected to a showerhead serving as a counter electrode, and the high-frequency power source for ion drawing is connected to the support table;

Figs. 7a and 7b are sectional views each showing an example of a structure of a wafer to which the plasma-etching process of the present invention is applied;

Fig. 8 is a view showing the relationship between self-bias voltage Vdc and a plasma density Ne of a plasma of gaseous argon, when a frequency of a high-frequency power is varied at 40 MHz and 100 MHz;

Fig. 9a is a view showing the uniformity in plasma

REPLACED BY
ART 34 AMDT

ionization accelerating gas to a molecular gas such as N_2, H_2, O_2, CO, NH_3, C_xH_y (in which x and y are natural numbers). The term "ionization accelerating gas" means a gas that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above. By adding such an ionization accelerating gas, a plasma distribution can be significantly improved, without lowering a plasma density (electron density).

The ionization accelerating gas is preferably Ar, Xe, or Kr. Of these gases, Ar is particularly preferred. When Ar is ionized from its ground state, an ionization energy of 15.8 eV is required, which value is not so different from that of an ionization energy of the molecular gas such as N_2 and H_2. However, Ar has metastable states which can be maintained for about five seconds at the energy levels of 11.55 eV and 11.72 eV from the ground state. Ar can make transition from the metastable states to the ionized state with an energy of about 4 eV. In addition, As shown in Fig. 3, the maximum ionization cross-section of Ar is about 3×10^{16} cm^2, which is larger than that of the molecular gas such as N_2 and H_2. Thus, addition of Ar to the process gas remarkably accelerates an ionization of the process gas. Xe and Kr also have metastable states and make transition therefrom to the ionized state with relatively low energies. In addition, as shown in Fig. 4, Xe and Kr have a maximum ionization cross-section larger than that of Ar. As shown in Fig. 4, although a rare gas similar to the above gases, He and Ne have a smaller maximum ionization cross-section. Further, He and Ne require a larger ionization energy. For example, He is ionized from the ground state with an ionization

REPLACED BY
ART 34 AMDT

Rec'd PCT/PTO 07 MAR 2006

table 2 serving as a support electrode is 500 V or below, preferably, 200 V or below.

As stated above, when a frequency of the high-frequency power for generating the plasma is as high as 40 MHz or above, an absolute value of the self-bias voltage is as low as 500 V or below. Thus, even when an atomic gas such as Ar having a large etching action is used as a process gas, an energy thereof is restrained so that the gas does not exert a high etching performance on the inorganic material film 43. Rather, use of a gas that is ionized with a low energy and has a large ionization cross-section, which gas is represented by Ar gas, can provide a uniform electron density or plasma density. In this embodiment, as described above, addition of an ionization accelerating gas represented by Ar, Xe, and Kr, that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above, promote an ionization of the process gas. Thus, the process gas can be sufficiently ionized near the edge portion of a substrate where an electric field strength is low, whereby the process gas can be uniformly ionized as a whole. As a result, a uniform electron density or plasma density can be achieved.

Experiment results demonstrating the above explanations are described below. Figs. 9a and 9b are views each showing a uniformity in plasma density (electron density) of the respective gases. In this experiment, a relationship between a radial position of a wafer 300 mm in diameter and a plasma density was examined, when a high-frequency of 100 MHz was applied to a support electrode at different powers of 2400 W and 1200 W, under the conditions that a pressure in a process vessel was

REPLACED BY
ART 34 AMDT

variations are possible therein.

For example, in the above embodiment, a plurality of segment magnets of permanent magnets are annularly disposed around a process vessel so as to form a ring magnet in a multipole condition as magnetic field forming means. However, the present invention is not limited thereto, as far as the magnetic field forming means can form a magnetic field around a process space to confine therein plasma. Such a peripheral magnetic field for confining plasma is not necessarily required, and it is possible to carry out an etching process without magnetic field. Alternatively, it is possible to carry out a plasma-etching in a cross-electromagnetic field by applying a horizontal magnetic field to the process space.

In the above embodiment, the low-k film is used as an organic material film. However, other organic material films for use in a multilayer resist may be employed.

Although Ar is mainly described as an ionization accelerating gas, and Xe and Kr are taken as examples, any gas may used as far as the gas is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above.

Moreover, in the above embodiment, the organic material film is etched with the inorganic material film used as a mask. Not limited thereto, the present invention can be applied to all the processes in which an organic material film should be selectively etched relative to an inorganic material film. For example, the present invention can be applied to an ashing process for removing a resist that has been used as a mask in an etching process of an inorganic material film such as SiO_2

CLAIMS

1. A method of plasma-etching an organic material film formed on a substrate by means of a parallel plate type plasma-etching apparatus; wherein

the organic material film is plasma-etched with a high-frequency power of a frequency of 40 MHz or above for generating plasma, and a process gas including a gas that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above.

2. The method according to claim 1, wherein

a plasma-etching apparatus is used, the apparatus including: a process vessel into which the process gas is supplied; and parallel plate electrodes disposed in the process vessel, the electrodes being constituted by a support electrode on which the substrate is supported, and a counter electrode that is opposed to the support electrode; and

the high-frequency power for generating the plasma is applied to the support electrode.

3. The method according to claim 2, wherein

a high-frequency power of a frequency of 500 kHz to 27 MHz for drawing ions is further applied to the support electrode, such that an absolute value of the self-bias voltage of the support electrode is 500 V or below.

4. The method according to claim 1, wherein

a plasma-etching apparatus is used, the apparatus

including: a process vessel into which the process gas is supplied; and parallel plate electrodes disposed in the process vessel, the electrodes being constituted by a support electrode on which the substrate is supported, and a counter electrode that is opposed to the support electrode; and

the high-frequency power for generating the plasma is applied to the counter electrode; and

a high-frequency power of a frequency of 500 kHz to 27 MHz for drawing ions is applied to the support electrode, such that an absolute value of the self-bias voltage of the support electrode is 500 V or below.

5. The method according to claim 3, wherein
the process gas includes Ar, N_2, and H_2.

6. The method according to claim 3, wherein
the process gas includes Ar and NH_3.

7. The method according to claim 3, wherein
a frequency of the high-frequency power for generating the plasma is 100 MHz.

8. The method according to claim 3, wherein
a distance between the support electrode and the counter electrode in the parallel plate electrodes is 40 mm or below.

9. An apparatus for plasma-etching an organic material film formed on a substrate, comprising:

a process vessel that contains the substrate;

parallel plate electrodes disposed in the process vessel,

the electrodes being constituted by a support electrode on which the substrate is supported, and a counter electrode that is opposed to the support electrode;

a process gas supply system that supplies a process gas into the process vessel;

an evacuating system that evacuates an atmosphere of the process vessel; and

a first high-frequency power source that supplies a high-frequency power for generating plasma to the support electrode; wherein

the first high-frequency power source supplies a high-frequency power of a frequency of 40 MHz or above; and

the process gas supply system supplies a process gas including a gas that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above.

10. The apparatus according to claim 9, further comprising:

a second high-frequency power source that supplies a high-frequency power of a frequency of 500 kHz to 27 MHz for drawing ions to the support electrode, such that an absolute value of the self-bias voltage of the support electrode is 500 V or below.

11. An apparatus for plasma-etching an organic material film formed on a substrate, comprising:

a process vessel that contains the substrate;

parallel plate electrodes disposed in the process vessel, the electrodes being constituted by a support electrode on

which the substrate is supported, and a counter electrode that is opposed to the support electrode;

a process gas supply system that supplies a process gas into the process vessel;

an evacuating system that evacuates an atmosphere of the process vessel;

a first high-frequency power source that supplies a high-frequency power for generating plasma to the counter electrode; and

a second high-frequency power source that supplies a high-frequency power for drawing ions to the support electrode; wherein

the first high-frequency power source supplies a high-frequency power of a frequency of 40 MHz or above;

the second high-frequency power source supplies a high-frequency power of a frequency of 500 kHz to 27 MHz, such that an absolute value of the self-bias voltage of the support electrode is 500 V or below; and

the process gas supply system supplies a process gas including a gas that is ionized from a ground state or metastable state with an ionization energy of 10 eV or below and has a maximum ionization cross-section of 2×10^{16} cm^2 or above.

12. The apparatus according to claim 10, wherein

a frequency of the high-frequency power supplied by the first high-frequency power source is 100 MHz.

13. The apparatus according to claim 10, wherein

a distance between the support electrode and the counter

electrode in the parallel plate electrodes is 40 mm or below.

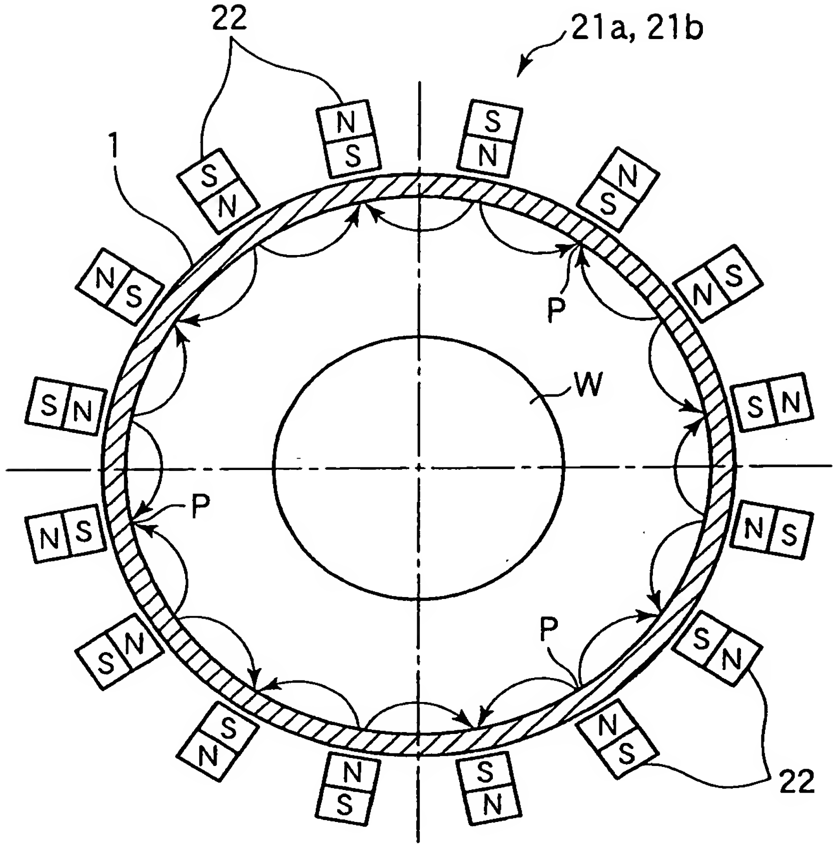

22
21a, 21b
1
N
S
P
W
22

FIG. 2

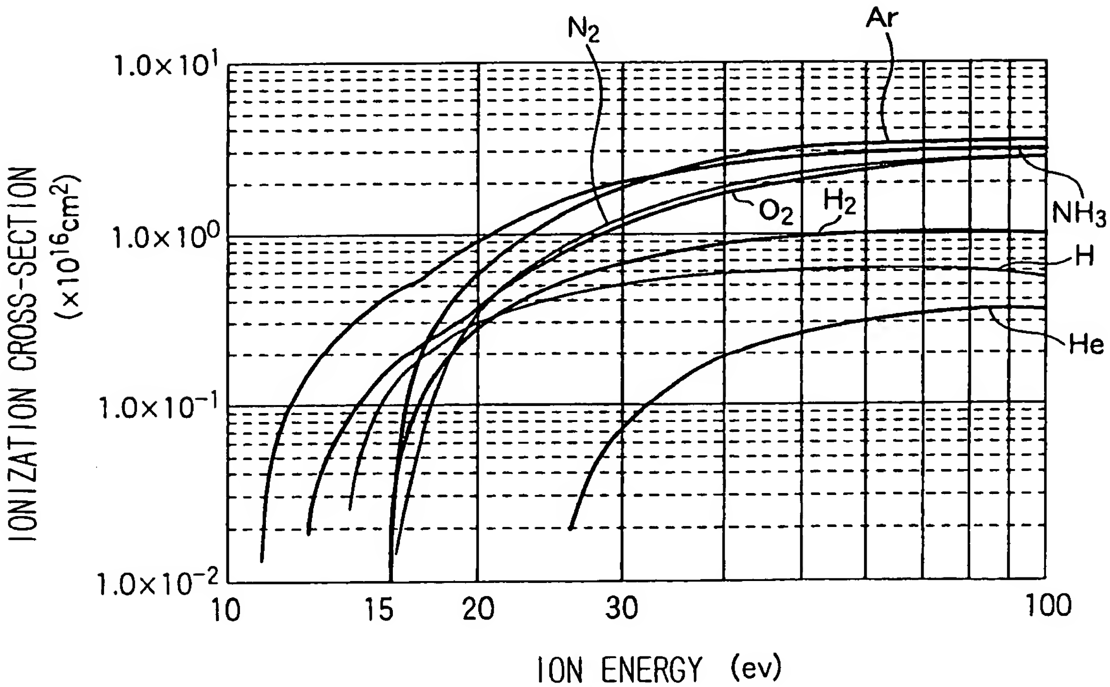
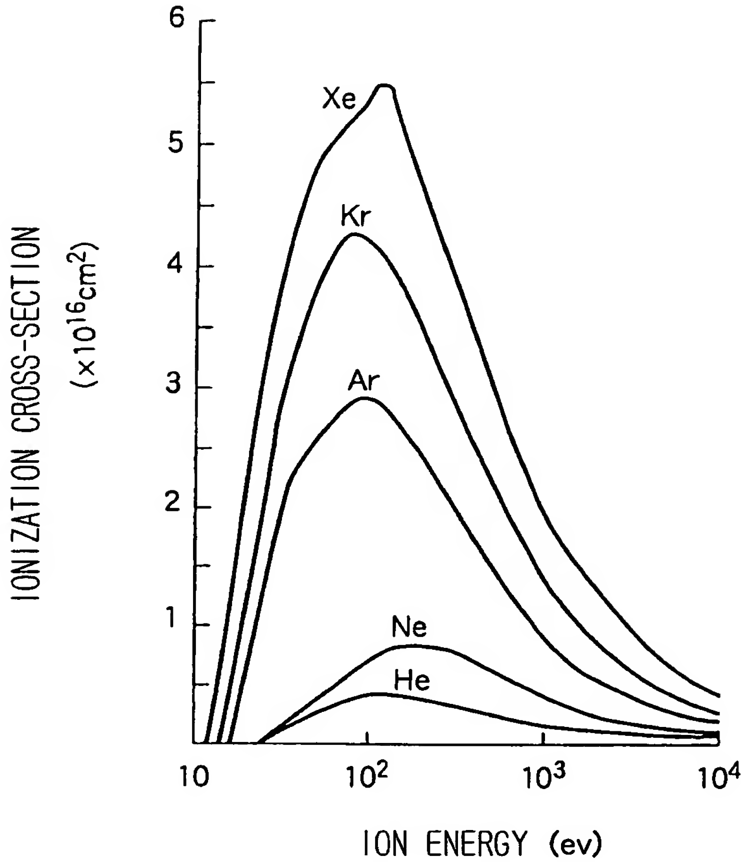
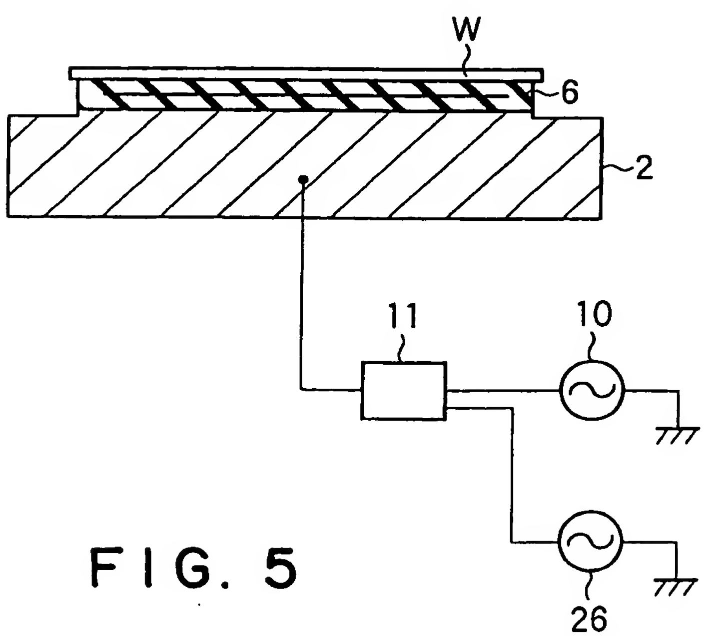

N2
Ar
1.0×10¹
1.0×10⁰
1.0×10⁻¹
1.0×10⁻²
IONIZATION CROSS-SECTION (×10¹⁶cm²)
O2
H2
NH3
H
He
10
15
20
30
100
ION ENERGY (ev)

FIG. 3



6
5
4
3
2
1
Xe
Kr
Ar
Ne
He
IONIZATION CROSS-SECTION
($\times 10^{16}$cm^2)
10
10^2
10^3
10^4
ION ENERGY (ev)

F I G. 4



W
6
2
11
10
26

F I G. 5